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Perfect Crystal device Technology

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Diffusion-induced dislocation relaxes the strain in the diffused layer appearing during the high concentration diffusion processes of impurities such as B and P. The conditions of the generation of diffusion-induced dislocation and dislocation-free high concentration diffusion are discussed in this report, referring to the electric characteristic of dislocation-free semiconductor divices.

1. Dislocation generation condition in high concentration diffusion process

Dislocations was harder to generate in the diffusion process of doped oxide than in the $POCl_3$ or BN diffusion process in which the surface concentration was not controlled under the solid solubility limit. Dislocation was considerably easier to be induced, during P or P-As doped oxide diffusion, into substrate with dislocations than into substrate without dislocations. In the case of B doped oxide diffusion, the generation of diffusion-induced dislocation was hardly affected by the grown-in dislocation. In the case of N type silicon (P diffusion), the increase of electron density will make it easy to move dislocation and this moving dislocation will cause multiplication, while in P type silicon (B diffusion) case, it will hardly affect such movement of the grown-in dislocation, which will hardly be the nucleation center of diffusion-induced dislocation. In the case of B diffusion at 1100°C, critical concentration for the generation of the dislocations was $1.4 - 1.6 \times 10^{16}/cm^2$ in terms of total diffused boron quantity instead of its surface concentration. Prussin's model cannot explain this and Shockley-Queisser's model can only qualitatively. Czaja suggested that critical surface concentration changes according to the diffusion condition. The critical total duffused boron quantity obtained from calculation based on his theory is $1.1 - 1.3 \times 10^{16}/cm^2$, which agrees with the experimental result. Similarly, in the case of 4 hour P diffusion at 1100°C, the theoretical critical total diffused phosphorus quantity is $7.1 \times 10^{16}/cm^2$, which thoroughly agrees with the experimental result of $6.6 \times 10^{16}/cm^2$.

2. High concentration diffusion without dislocations

Dislocation-free high acceptor-concentration diffusion was possible by simultaneous diffusion of B and Ga which is larger in atomic radius than silicon. As for dislocation-free diffusion condition obtained from electrical measurement for B-Ga closed coupsle diffusion at 1260°C, the concentration ratio of (B/Ga) was 0.5 - 0.7 showing that measured B concentration was larger than theoretical one (0.3).

High donor concentration dislocation diffusion without dislocation was possible by simultaneous diffusion of P and small amount of As or Sb. In the case of 4-hour diffusion from P-As mixed doped oxide at 1100°C, As and P were distributed as shown in Fig. 1. The concentration of As is one-tenth lower than that of P. This dislocation-free diffusion is not based on the mechanism of compensating the strain by atomic radius difference between As and P but on a new mechanism. P-Sb dislocation-free diffusion cannot be explained too by the stain compensation mechanism but may be explained by the new mechanism. The measurement by X-ray double crystal diffraction technique gave the same strain in the diffused layer for both cases of P alone and P-As diffustion. Noteworthy fact is that As pile-up near the surface was found in the distribution of As diffused with P. It was detected through the radioactive analysis, ion mass micro-analysis and helium ions backscattering. Arsenic in the pile-up layer is considered to be located in the non-lattice sites and to enlarge the lattice constant of the surface. The measurement of duffused silicon substrate curvature sometimes, in P-As diffusion case, showed convex diffused layer which indicates the existence of layer of large lattice constant. The emitter dip effect observed in base and emitter duffusion from various impurity sources is shown in Table-1. The emitter dip effect due to dislocations by BN base-diffusion was found. Even in case base and emitter were diffused without dislocation, the effect appeared unless P-As emitter diffusion was carried. In the donor diffusion case, vacancy concentration generally increases in proportion to electron density while in arsenic diffusion case, vacancy-arsenic complex is formed, which causes undersaturation of vacancy concentration and emitter retardation effect. In P-As diffusion case, the excess vacancies due to high concentration of P will be trapped through formation of vacancy-arsenic complex, which causes neither supersaturation nor undersaturation of vacancy in the whole diffused layer and thus formation of no dislocation-loop. Interstitial As pile-up near the surface will enlarge the lattice constant and prevent the surface from working as nucleation site for the diffusion-induced dislocations. Therefore, in P-As diffusion case, dislocation won't be induced by the strain in the diffused layer as there is no nucleation center of dislocation both on the crystal surface and its inside.

3. Electric characteristic of the devices without dislocations

The devices manufactured by the conventional processes is compared with ones manufactured by the above new method, Perfect Crystal device Technology (PCT). We have made it clear through detail analysis of gated NPN transistor's noise characteristics that not only the surface state but the crystal defects within the active base region could be the noise source. Fig. 2 shows the effect of elimination of dislocations in the devices that 1/f noise figure was improved to a considerable extent in the devices made through PCT. As for the devices by PCT, burst noise disappears. Emitter-base reverse current is reduced. The current gain generally increases with temperature increase. Fig. 3 shows that devices by PCT has lower temperature-dependance of current gain than the devices by the conventional processes. Buhanan pointed out that band gap decrease due to the strain in the high concentration diffused region or due to the diffusion-induced dislocation increases the temperature dependance of current gain. Thus, dislocation-free devices by PCT contribute greatly to the improvement of their electric characteristics and the practical application for high frequency devices using precision control of base width, because no emitter-dip effect appears in PCT. It also features low-stress in P-As doped oxide film.

Emitter		Base		Base Width		
Source	Dislo-cation	Source	Dislo-cation	W_B	ΔW_B	$\Delta W_B / W_B$
$POCl_3$	Yes	BN	Yes	0.60μ	0.30μ	50%
$POCl_3$	Yes	BSG	No	0.80	0.25	31
PSG	No	BN	Yes	0.76	0.20	27
PSG	No	BSG	No	0.35	0.05	14
P-As	No	BN	Yes	0.52	0.06	12
P-As	No	BSG	No	0.31	0.00	0

Table 1 Emitter dip effect in NPN transistor
BSG, PSG and P-As signify oxide doped with B, P, P-As respectively. W_B and ΔW_B are base width and emitter di

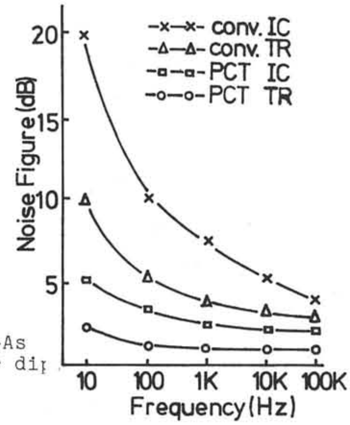

Fig. 2 Low frequency noise in IC and transistor manufactured by conventional processes or PCT.

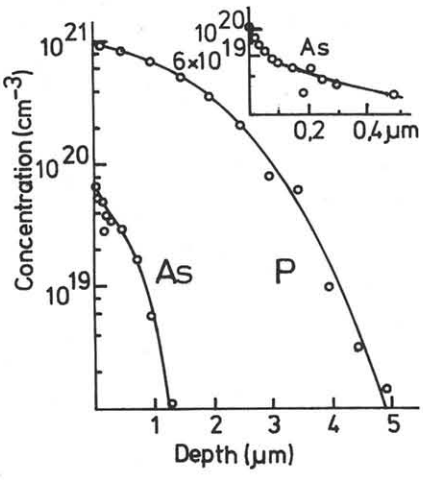

Fig. 1 Distribution of P and As observed by radioactive analysis.

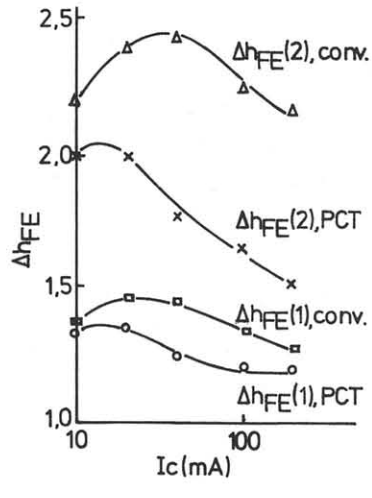

Fig. 3 Temperature dependence of current gain. $\Delta h_{FE}(1)=h_{FE}(100°C)/h_{FE}(25°C)$,
$\Delta h_{FE}(2)=h_{FE}(100°C)/h_{FE}(-50°C)$.